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Observations of the Solar Particle Event of 5 to 12 February 1965 with Mariner IV and Injun IV

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ABSTRACT

The solar cosmic ray event of 5-12 February 1965 is the most intense one of a ten month period of interplanetary observation (28 November 1964 - 30 September 1965) with Mariner IV during the recent epoch of minimum solar activity. A full time history of the intensities of energetic particles is presented from onset at 1835 ± 10 U.T. on 5 February following a 2^+ solar flare N08, W25 (which began at 1750 U.T.) until disappearance into the background near the end of 12 February. A mixture of low energy protons $E_p > 0.5$ MeV and electrons $E_e > 40$ keV is identified in this event for the first time. Maximum values of intensities early in the event are as follows:

Protons:

$$j = 108\ (\mathrm{cm}^2\ \mathrm{sec\ ster})^{-1} \text{ for } 0.50 < E_p < 11 \text{ MeV;}$$
$$j = 45\ (\mathrm{cm}^2\ \mathrm{sec\ ster})^{-1} \text{ for } 0.88 < E_p < 4.0 \text{ MeV;}$$
$$J_o = 80\ (\mathrm{cm}^2\ \mathrm{sec})^{-1} \text{ for } E_p \gtrsim 55 \text{ MeV.}$$

Electrons:

$$j = 700\ (\mathrm{cm}^2\ \mathrm{sec\ ster})^{-1} \text{ for } E_e > 40 \text{ keV.}$$

Simultaneous observations with similar equipment on the near-earth satellite Injun IV are compared with those of Mariner IV. It is

found that the time histories of the intensities of both low energy, $E_p \sim 1$ MeV, and higher energy, $E_p \sim 55$ MeV, protons over the polar caps of the earth are similar to those at a position 0.15 A.U. from the earth. The propagation of protons with $E_p \gtrsim 55$ MeV is apparently diffusive, with a diffusion coefficient increasing with heliocentric radial distance as $r^{2/3}$. Propagation of the low energy protons is not consistent with any simple model of interplanetary diffusion. The time profile of these particles reveals a spatial structure of $\sim 4 \times 10^5$ km. Such particles are shown to have been distributed over a heliocentric longitudinal range of at least 70° in interplanetary space if the model of solar co-rotation of a general magnetic field line structure be taken to govern the time history of their intensity.

The time history of the intensity of low energy electrons is also presented.

INTRODUCTION

Studies of solar cosmic rays in recent years have produced a large body of information concerning their composition, energy spectra, time history, and angular distributions and concerning their propagation through the interplanetary medium and penetration into the geomagnetic field. We report herein observations of the solar particle event which began on 5 February 1965; these observations were obtained with University of Iowa equipment on the Mars-bound spacecraft Mariner IV at a point remote from the earth and with similar detectors on our Injun IV near-earth satellite. Early examples of the simultaneous observation of solar cosmic rays with two widely separated spacecraft were in late March - early April 1960 with Explorer VII [Van Allen and Lin, 1960] and Pioneer V [Fan, Meyer, and Simpson, 1960] [Arnoldy, Hoffman, and Winckler, 1960], and in late September - early October 1961 with Injun I [Van Allen and Whelpley, 1962] and Explorer XII [Van Allen, Rosser, and Whelpley, 1962].

Our data for the 5 February event are of particular interest for several reasons:

(a) The event is the most intense one during some ten months (28 November 1964 - 30 September 1965) of interplanetary observations with Mariner IV during an epoch of minimum solar activity. Also its temporal and spectral characteristics are quite different than those of any other event during that period [Krimigis and Van Allen, 1966].

(b) The radiation reaching Mariner IV consists of a mixture of protons and electrons [cf. Van Allen and Krimigis, 1965 and 1966]. No such event has been observed previously.

(c) Simultaneous observations with similar detectors are available in interplanetary space with Mariner IV and near the earth with Injun IV.

Two other sets of observations on this event with other types of detectors in near-earth satellites are reported elsewhere [Paulikas, Freden, and Blake, 1966] [Bostrom, Kohl, and Williams, 1967] [Williams and Bostrom, 1967], as are simultaneous observations with other apparatus on Mariner IV and on IMP II [O'Gallagher and Simpson, 1966].

Using the Mariner IV data, the incident particles are identified and the association is developed between an optical flare on the sun, the particle increase and subsequent decay, and various geophysical phenomena as observed at the earth. The Injun IV data provide the opportunity for a direct comparison between particle intensity variations at the earth and in interplanetary space.

DETECTORS

The University of Iowa package of particle detectors on Mariner IV has previously been described in detail [Van Allen and Krimigis, 1965] [Krimigis and Armstrong, 1966]. Briefly, it consists in part of three end-window type GM tubes having electron energy thresholds of 40 keV (Detector B), 45 keV (Detector A), and 150 keV (Detector C) for particles entering through their collimators. The corresponding proton energy thresholds are 0.55 MeV, 0.67 MeV, and 3.1 MeV, respectively. Their omnidirectional characteristics are essentially identical with an effective threshold of ~ 55 MeV for protons. In addition to the GM tubes there is a thin (~ 35 microns) surface barrier solid state detector responding to protons in the energy ranges $0.50 \leq E_p \leq 11$ MeV (Detector D_1) and $0.88 \leq E_p \leq 4$ MeV (Detector D_2) and insensitive to electrons of any energy. Each of the five detectors has a conical collimator with a full vertex angle of 60°. The sidewall shielding of the solid state detector also has a minimum thickness corresponding to the range of ~ 55 MeV protons. The angles between the axes of the detectors and the primary axis of the spacecraft as well as their orientation with respect to the sun-spacecraft line are shown in Figure 1. The properties of the Mariner IV detectors are summarized in Table 1.

The Injun IV detectors which are relevant to the present study are the following: (a) An EON 5112 GM tube whose energy threshold for protons is ~ 27 MeV. (b) A heavily shielded EON 6213 GM tube whose energy threshold for protons is ~ 70 MeV. Both of these detectors have been described previously [Ludwig and Whelpley, 1960] [Van Allen, 1966]. (c) A 25 micron surface barrier, totally depleted solid state detector with its energy discrimination levels set for protons in the energy range $0.516 \leq E_p \leq 4.2$ MeV (Detector A) and $0.90 \leq E_p \leq 2.1$ MeV (Detector B). These channels are insensitive to electrons of any energy. The detector has a conical collimator with full vertex angle 40° and is otherwise shielded by a minimum of 10.2 g/cm^2 of brass, which corresponds to the range of 95 MeV protons. The characteristics of the Injun IV detectors are summarized in Table 2.

The estimated contribution to the counting rate of the Mariner solid state detector during this event due to particles penetrating the shielding and crossing the detector sideways is at most comparable to the background counting rate due to the in-flight source, namely ~ 0.07 counts per second; the corresponding contribution to the counting rate of the Injun IV solid state detector is at least a factor of four less than the in-flight source background of 0.07 counts per second. Therefore, only particles coming through the collimator and belonging to the appropriate energy interval contribute significantly to the counting rate of any of the solid state detectors.

REMARKS ON DATA

Analysis of the data from Mariner IV is straightforward since the spacecraft is oriented continuously with the detectors' axes at fixed angles to the sun-spacecraft line (Figure 1) and the data flow is substantially continuous.

The Injun IV satellite was launched on 21 November 1964 into a nearly polar orbit of 81° inclination, with an initial apogee altitude of 2502 kilometers and a perigee altitude of 527 kilometers. The satellite is equipped with a permanent magnet and energy-dissipating hysteresis rods so that it will maintain one axis aligned with the geomagnetic field vector. Due to weak damping, stable alignment does not occur until latter February. During the period 5-8 February, the satellite is still tumbling with a period of approximately one minute. Hence, solid state detector data from both real-time and tape-recorded segments over the polar caps are selected for only those periods during which the detector is viewing directions outside of the loss cone. All such data from positions for which $L > 8$ are averaged for each available pass (typically 6 to 15 minutes) to yield a single counting rate which is assigned to the mid-time of the pass.

SOLAR TERRESTRIAL EVENTS

On 5 February 1965 a flare of importance 2^+ occurred on the sun beginning at 1750 U.T. and ending at 2024 U.T. At approximately the same time, intense solar radio emission was observed at several frequencies beginning with 2800 megacycles and ending with a continuum in the range of 22 to 41 megacycles. Some relevant data are summarized in Table 3.

We attribute the particles observed by Mariner IV and Injun IV to this flare.

PARTICLE OBSERVATIONS

The position of Mariner IV at a representative time is given below in geocentric solar ecliptic coordinates:

On 5 February 1965 at 2000 U.T.

$x = -23,032,480$ km ($3611\ R_E$) (0.153 A.U.)

$y = +\ 3,850,260$ km ($604\ R_E$)

$z = +\ \ 350,410$ km ($54.9\ R_E$)

$\theta = +\ 0.86°$

$180 - \varphi = 9.49°$

At the same time, the heliocentric radial distances of the spacecraft and the earth are 170,606,480 km (1.140 A.U.) and 147,530,170 km (0.986 A.U.) respectively and the heliocentric ecliptic longitudes of the spacecraft and the earth differ by 1.29°, the spacecraft being clockwise of the earth as viewed from the north ecliptic pole.

Figure 2 shows the early portion of the event as seen by the three Geiger tubes on Mariner IV. The extrapolated onset time is 1835 U.T. $\pm$ 10 minutes for all three detectors; maximum counting rates occur in the time range 20 to 22 hours U.T. Further detailed features of these curves and the significance of same will be discussed in a later section.

The overall time history of enhanced counting rates of the five detectors is shown in Figure 3 for the period 3-14 February, in the form of three-hour averaged rates.

Counting rate data in full detail are shown in Figure 4 for the first three and a half days.

In Figure 5, through the courtesy of other observers, we have plotted relevant geomagnetic, riometer, and neutron monitor data for comparison with the counting rate curve of Detector C.

The corresponding data from Injun IV, though necessarily intermittent, are of interest in their own right and are of further significance when taken together with those from Mariner IV. A sample pass of data from the large omnidirectional Geiger tube on Injun IV is shown in Figure 6. The difference in plateau counting rates over the polar cap on this occasion and on a quiet day is taken to represent the contribution of solar cosmic rays which have penetrated the geomagnetic field.

The time histories of plateau counting rates of the large Geiger tube (112) and of the smaller, more heavily shielded one (SpB) are shown in Figure 7 for a three day period - 5, 6, and 7 February. They are seen to be generally similar to that of Detector C in Mariner IV.

The solid state detector on Injun IV was designed primarily for study of geomagnetically trapped ions and had, therefore, a directional geometric factor of 0.10 of that on Mariner IV (Tables 1 and 2). The respective detectors, are, however, very similar in all other respects and have similar energy band-passes.

In Figure 8 we show a smooth curve through the one-hour averaged net counting rates of Detector D_1 on Mariner IV and superimposed on it, after an upward displacement of one decade, the individual polar cap ($L > 8$) averages of the net rate of Detector A on Injun IV. The respective in-flight calibration source rates have been subtracted from the total rate in both cases. Thus, this figure provides a detailed comparison of the absolute directional intensities at the position of Mariner IV and over both northern and southern polar caps of the earth. A similar presentation of the net counting rates of Detector D_2 on Mariner IV and of Detector B on Injun IV is given in Figure 9.

TIME HISTORY OF THE INTENSITY OF PROTONS $E_p \gtrsim 55$ MeV

The time history (Figure 4) of the counting rate of Detector C on Mariner IV appears to have a shape which is characteristic of interplanetary diffusion theory.

In order to examine this point more thoroughly, a net counting rate curve due to penetrating solar protons only is found by first subtracting the background rate due to galactic cosmic rays, then subtracting the estimated contribution due to protons $3.1 < E_p < 55$ MeV by use of the spectrum derived from D_1 and D_2. The latter correction is trivial for times before 0400 on 6 February. It is found that the corrected intensity-time curve is well fitted by the assumption of spherically isotropic interplanetary diffusion with a diffusion coefficient $D \propto r^{\beta}$ with $\beta = 2/3$, where r is heliocentric radial distance (Figure 10) [cf. Krimigis, 1965]. This result is equally valid for diffusion in a conical region whose vertex is at the source and whose side wall is bounded by radial lines through the source. The above analysis also yields 3×10^{31} particles/steradian ($E_p > 55$ MeV) emitted at the sun [Krimigis, 1966].

TIME HISTORY OF THE INTENSITY OF PROTONS
$E_p \sim 1$ MeV

The time history of the low energy protons ($E_p \sim 1$ MeV) is, however, quite different (Figure 3) and has no resemblance to the expectation of any simple diffusion model which has been proposed. This impression is further confirmed by Figure 11, which gives two samples of a family of unsuccessful attempts to obtain a linear relationship between log $[I\ t^{3/(2-\beta)}]$ and t^{-1}. It is, of course, certain that diffusion does have a role in the interplanetary propagation of low energy particles but it now seems likely that continuing acceleration and/or delayed release from the sun and quasi-trapping along interplanetary field lines of complex shape also contribute in an important way to the intensity-time curves for such particles. The complexity of the process is illustrated by the detailed structure of the time profile. For example, at 0030 U.T. on 7 February there is a statistically significant peak in the D_1 counting rate of 0.5 hour time width, corresponding to a spatial structure of $\sim 4 \times 10^6$ km. At $\sim$ 1200 U.T. on the same day significantly different counting rates occur on successive detector readings at a time spacing of

200 seconds, corresponding to a spatial structure of 4×10^5 km. In the foregoing estimates the assumed value of the velocity of transport of inhomogeneities is 2000 km/sec. Such a value corresponds to the delay of 20 hours between the flare and the occurrence of the SC at the earth. Of further interest in this connection is the sharp increase by a factor of two in the counting rate of D_1 at 1710 on 6 February, three hours after the SC at the earth (which is 23,000,000 km closer to the sun).

The spectrum of the low energy protons exhibits a significant change with time as evidenced by the time dependence of the D_1/D_2 counting rate ratio. The value of the energy parameter E_o in a two-point spectral fit of the form $dj/dE = K\, e^{-E/E_o}$ is shown as a function of time in Figure 12. The dominant tendency is toward a more steeply falling spectrum after mid-day on the 6th of February. Hence the more energetic particles escape from the observational system more rapidly than do the lower energy ones. During the first few hours of the event it is evident on the basis of time-of-flight considerations alone that the responses of both D_1 and D_2 are due to particles in the high energy edges of their energy pass bands.

IDENTIFICATION OF SOLAR ELECTRONS AND THEIR TIME HISTORY, INTENSITY, AND SPECTRA

As shown best in Figure 4, the major maxima of the counting rates of Detectors A, B, and C on Mariner IV occur at such an early time that the contribution of protons of energy $E_p < 11$ MeV is negligible. Also, protons $10 < E_p < 55$ MeV entering through the collimator of Detector C contribute less than 10% of its counting rate for (at least) the first 12 hours of the event, a result derived from data from a large GM tube with a 10 MeV proton threshold, also on Mariner IV (courtesy of H. R. Anderson prior to publication). Hence the responses of A, B, and C during the early portion of the event must be attributed primarily to protons capable of penetrating the side wall shielding of the tubes and/or to electrons entering the tubes through their collimators. This was, in fact, the first solar event which led us to the working hypothesis that electrons of $E_e \sim 40$ keV are emitted impulsively in solar flares with detectable intensities. Our later detection and study of "pure" electron events, also with Mariner IV [Van Allen and Krimigis, 1965], confirms this hypothesis in a conclusive way and contributes to our confidence that the 5 February 1965 flare emitted a <u>mixture</u> of protons and electrons [Van Allen and Krimigis, 1966]. The argument proceeds as follows:

(a) Detectors A, B, and C have identical side wall shielding.

(b) The Geiger tubes themselves are nominally identical and exhibit the same galactic cosmic ray counting rates $\pm$ 10%. Hence, they have about the same omnidirectional geometric factors.

(c) The energy thresholds for electrons entering the detectors through the collimators of B, A, and C are (Table 1) 40, 45, and 150 keV, respectively. The respective observed maximum counting rates (Figure 2) are 50, 30, and 12 counts per second--i.e., in exactly the inverse order to their thresholds.

(d) The values of the counting rate ratios A/C and B/C are much too large to be attributed to the minor differences in the shielding of the detectors as they are actually mounted on the spacecraft <u>if</u> the rates of these detectors are thought to be due solely to penetrating protons. Moreover, Detector B has more incidental shielding than does either A or C.

(e) The maximum net counting rate of another similar, but fully and more heavily shielded, detector SpB on Injun IV (insensitive to electrons of $E_e \lesssim 1$ MeV) is 5.4 counts per second. In view of the fact that its energy threshold is about 70 MeV and that it is shielded over π steradians by the earth, we believe that it is reasonable to attribute the counting rate of Detector C early in the event to protons of $E_p > 55$ MeV only.

(f) Later solar electron events in May and June 1965 have a very small component of electrons of sufficient energy to penetrate the window of Detector C [Van Allen and Krimigis, 1965].

(g) Thus we attribute the response of Detector C early in the event primarily to penetrating protons $E_p > 55$ MeV. The estimated maximum value of the omnidirectional intensity is $J_o \sim 80/\mathrm{cm}^2$ sec $E_p > 55$ MeV, a result which appears to be in crude agreement with that of Paulikas et al. The various bodies of data which have been mentioned previously are difficult to harmonize on an absolute spectral basis. But we do find that at $\sim$ 0100 U.T. on 6 February, a reasonable reconciliation to a factor of ~ 2 is represented by the integral magnetic rigidity spectrum for the unidirectional intensity $j\ (>R) = 1200 \exp(-R/50)$, for $70 < R < 400$ MV. Using Figure 7 of Adams and Masley [1966], one may expect a cosmic radio noise absorption in the polar cap atmosphere at 30 mc/sec of 1.6 db, in good agreement with that observed (Figure 5) [see also Van Allen et al., 1964].

(h) In Figure 13 are given fully detailed plots of the time dependence of two quantities X and Y derived from Mariner IV data. Y is the counting rate of Detector C minus its pre-event galactic cosmic ray background. X is the counting rate of Detector B minus that of C and further minus the contribution of low energy protons

$0.55 < E_p < 3.1$ MeV as obtained from Detectors D_1 and D_2 (with an appropriate correction for relative geometric factors). It is seen that the time history of X is significantly different than that of Y in three respects. First, X rises more rapidly than Y at the beginning of the event. Secondly, X exhibits a number of large and significant time fluctuations, especially during the first three hours of the event, which are not present in Y. Thirdly, for the eight-hour period following 2200 U.T. on 5 February both X and Y decay exponentially but with significantly different time constants, namely 4.3 and 7.4 hours, respectively.

(i) On the strength of the evidence cited in the preceding paragraphs, we conclude that the quantity X represents the time history of the intensity of solar electrons $E_e > 40$ keV which are emitted impulsively by the 5 February flare in company with the more familiar protons. As noted before [Van Allen and Krimigis, 1965], interplanetary time histories of the intensity of such electrons and of protons $E_p \sim 20$ to 70 MeV are broadly similar. It is of some interest to note that the time fluctuations of the intensity of electrons early in the 5 February event have a quasi-periodic character with a period of ~ 45 minutes, reminiscent of that reported by Bryant et al. [1965] for 6-90 MeV protons on

28 September 1961. However, in the event reported herein there are no such fluctuations in the intensity of protons $E_p \gtrsim 55$ MeV (Y in Figure 13).

The unidirectional intensity of electrons has a maximum value of 700 $(cm^2 \text{ sec sterad})^{-1}$ at ~ 2020 U.T. on 5 February. Hence, this is the most intense solar electron event reported thus far [Van Allen and Krimigis, 1965] [Anderson and Lin, 1966].

DETAILED RELATIONSHIP BETWEEN LOW ENERGY PROTON DATA FROM MARINER IV AND INJUN IV

We turn now to the discussion of the comparative Mariner IV - Injun IV data of Figures 8 and 9. A further combination of these data with those from the earth satellite 1963-38C is treated by Williams and Bostrom in the accompanying paper. Our interpretation of Figures 8 and 9 is as follows:

(a) Broadly speaking, the absolute directional intensities of low energy protons in (nearly) identical energy channels are similar in interplanetary space and over the polar caps of the earth throughout the event - from onset to the end of the available Injun IV data.

(b) There are indeed differences in detail which are statistically significant.

(c) However, we are struck by the fact that the northern-southern hemisphere differences in the Injun IV data, especially during the first day, are at least as large as are the differences between Injun IV and Mariner IV data.

(d) In the framework of recent studies by the spinning spacecraft Pioneer VI [Fan et al., 1966] [Bartley et al., 1966] [McCracken and Ness, 1966] and Explorer 33 [Van Allen et al., 1967], we believe that the fine structure in Figures 8 and 9 is most reasonably attributed to time-varying anisotropy and absolute intensity of the solar proton beam in interplanetary space. If it is assumed that the interplanetary magnetic field is in the form of an Archimedes spiral co-rotating with the sun, then the relative positions of Mariner IV and Injun IV are such (see section entitled Particle Observations) that a given filamentary tube of particles which are assumed to be attached to a given line of force must rotate through a distance of $\sim$ 20,000,000 km after striking the earth (Injun IV) before it encounters Mariner IV. This distance corresponds to $\sim 10^3$ gyro radii of a 1 MeV proton in a 5 gamma magnetic field or to a time delay of $\sim$ 12 hours. The observed time delay in onset time is, however, 0 ± 2 hr (Figures 8 and 9). Nonetheless, on other occasions, substantial fluctuations in the intensity and angular distribution of solar particles are observed by Explorer 33 to occur with time scales as short as one minute. Hence, the intensity near the earth and at Mariner IV may reasonably be quite different at a given moment. Also on the basis of Explorer 33 data (during other events in 1966) the directional intensity measured at 70° to the sun-spacecraft line with Mariner IV may differ by factors of 2 to 5 from that in other directions. At the earth, the intensity over the north polar cap is probably due to particles moving dominantly southward in interplanetary space and over the south polar cap, dominantly northward. Hence the geomagnetic field itself is a crude directional analyzer.

(e) In the spirit of the foregoing discussion, we regard the similarities in the absolute values of Mariner IV and Injun IV intensities as more remarkable than the differences. The prolonged duration ($\sim$ three days) of intensities of the same order of magnitude does in fact require that the intensity be substantially the same over a cone of full vertex angle $\gtrsim 40°$ at the sun if one adopts the view that particle diffusion transverse to the average interplanetary magnetic field is much slower than diffusion parallel to the field. This angle must be further increased by $\sim 30°$ since the particles arrive promptly and simultaneously at the earth and at Mariner IV from the responsible solar flare at 25° W of the central meridian.

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TABLE 1

Characteristics of Detectors
Mariner IV

Detector	Unidirectional Geometric Factor, cm^2 ster	Omnidirectional Geometric Factor, cm^2	Particles to Which Sensitive Through the Collimator	Dynamic Range
A	0.044 ± 0.005	~ 0.15	Electrons: $E_e \gtrsim 45$ keV Protons: $E_p > 670 \pm 30$ keV	From galactic cosmic-ray rate of 0.6 c/s to 10^7 c/s
B	0.055 ± 0.005	~ 0.15	Electrons: $E_e \gtrsim 40$ keV Protons: $E_p > 550 \pm 20$ keV	From galactic cosmic-ray rate of 0.6 c/s to 10^7 c/s
C	0.050 ± 0.005	~ 0.15	Electrons: $E_e \gtrsim 150$ keV Protons: $E_p > 3.1$ MeV	From galactic cosmic-ray rate of 0.6 c/s to 10^7 c/s
D_1	0.065 ± 0.003	—	Electrons: None Protons: $0.50 \leq E_p \leq 11$ MeV	From in-flight source rate to 10^6 c/s
D_2	0.065 ± 0.003	—	Electrons: None Protons: $0.88 \leq E_p \leq 4.0$ MeV	From in-flight source rate to 10^6 c/s

Note: Detectors A, B, C, and D have side shielding corresponding to the range of a proton $E_p \sim 55$ MeV.

TABLE 2

Characteristics of Detectors
Injun IV

Detector	Unidirectional Geometric Factor, cm^2 ster	Omnidirectional Geometric Factor, cm^2	Particles to Which Sensitive	Dynamic Range
A	0.0064 ± 0.0007	—	Protons: $0.516 \leq E_p \leq 4.2$ MeV Electrons: None	From inflight source rate to 10^6 c/s
B	0.0064 ± 0.0007	—	Protons: $0.90 \leq E_p \leq 2.1$ MeV Electrons: None	From inflight source rate to 10^6 c/s
112	---	8.9^*	Protons: $E_p \gtrsim 27$ MeV ** Electrons: Insensitive except via bremsstrahlung for $E_e \gtrsim 1$ MeV	From galactic cosmic ray rate of 30.77 c/s to 10^5 c/s
SpB	---	~ 0.4	Protons: $E_p \gtrsim 70$ MeV Electrons: Insensitive except via bremsstrahlung for $E_e \gtrsim 1$ MeV	From galactic cosmic ray rate of 2 c/s to 2×10^5 c/s

*If exposed in free space. Effective geometric factor is smaller by ~ 30% as actually mounted in the satellite.

**This threshold corresponds to protons incident perpendicular to the axis of the cylindrical-type tube. For protons incident at an angle of 60° to the axis, the threshold is ~ 40 MeV.

TABLE 3

(Ref.: Compilations of Solar-Geophysical Data, U. S. Dept. of Commerce NBS/CRPL, Boulder, Colorado, March and June 1965)

Date and Time U.T.	Event	Comments
5 February 1965 1750-2024 Max. at 1810	2^{+} Flare N08, W25	McMath Plage Region 7661. Probable source of observed protons and electrons at Mariner IV and at earth.
1753-1930 Max. at 1826	Intense 2800 Mc/s Emission	
1835 ± 10 minutes	Beginning of particle increase at Mariner IV	
~ 1900	Beginning of PCA	
2200	Beginning of gradual Forbush decrease	
6 February 1414	Storm sudden commencement	

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CAPTIONS FOR FIGURES

Figure 1. The essential geometry of the detectors on Mariner IV. The spacecraft is continuously oriented to maintain its -Z axis through the sun. The thin window Geiger tubes A, B, and C are all shielded from light and soft x-rays from the sun.

Figure 2. Early time history of the event showing the determination of onset time.

Figure 3. An overall graphical summary of the time history of the event as found with five different detectors.

Figure 4. Plots in full available time detail for the first three and a half days of the event.

Figure 5. A summary plot of relevant terrestrial data for comparison with that from Detector C. Riometer data, courtesy of A. J. Masley. Deep River neutron monitor data, courtesy of J. F. Steljes. Note the absence of any detectable positive effect on 5-6 February in the latter data.

Figure 6. A sample pass of polar cap data during the height of the event from the large omnidirectional Geiger tube on Injun IV. The undulation of the counting rate at high latitudes is due to the slow tumbling of the satellite coupled with the partial shielding of the detector by the body of the satellite and the inevitable anisotropy of the radiation due to the presence of the earth.

Figure 7. Summary time history of the polar cap counting rates of two different Geiger tubes on Injun IV.

Figure 8. A composite plot of two sets of data obtained with similar solid state detectors on Mariner IV and Injun IV. The absolute directional intensities of solar protons are obtained by dividing the counting rates by 0.065 for Mariner IV and 0.0064 for Injun IV (Tables 1 and 2). The smooth curve is drawn through one-hour averaged counting rates of Mariner IV. Each plotted point represents a polar cap averaged counting rate for Injun IV. The respective sets of data as shown here are normalized to each other on an absolute basis.

Figure 9. Similar to Figure 8.

Figure 10. An interplanetary diffusion analysis of the time history of the corrected counting rate of Detector C for protons $E_p \gtrsim 55$ MeV.

Figure 11. A graphical study of the failure of conventional diffusion analysis to describe the time history of the intensity of protons $E_p \sim 1$ MeV.

Figure 12. Time history of the energy parameter E_o as derived from the D_1/D_2 counting rate ratio for an assumed exponential spectrum in particle energy.

Figure 13. Time histories of two quantities X and Y which are derived from Mariner IV data. X represents the time history of the intensity of electrons $E_e > 40$ keV. Y represents the intensity of protons $E_p > 55$ MeV (see text).

G 67-172

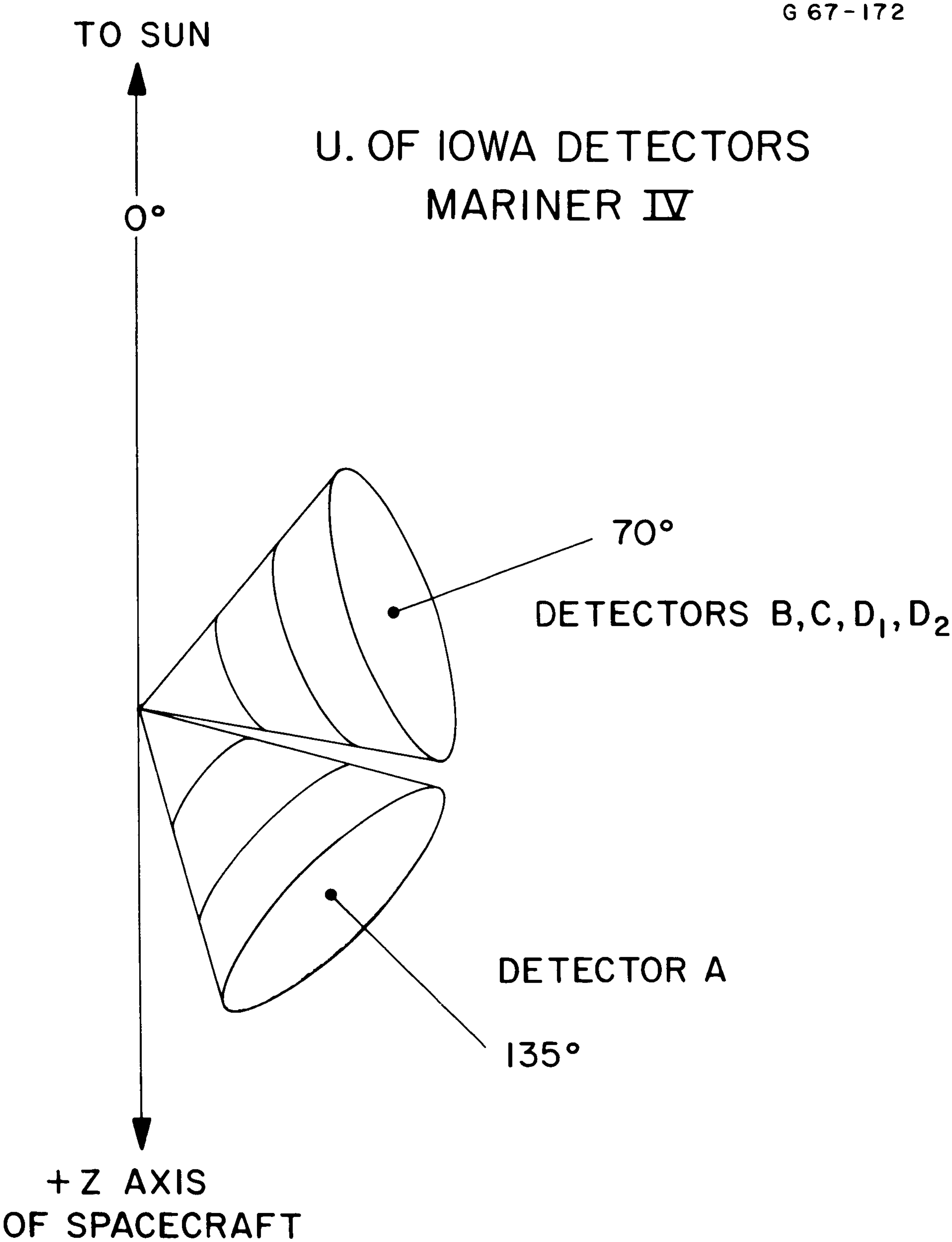


Figure 1

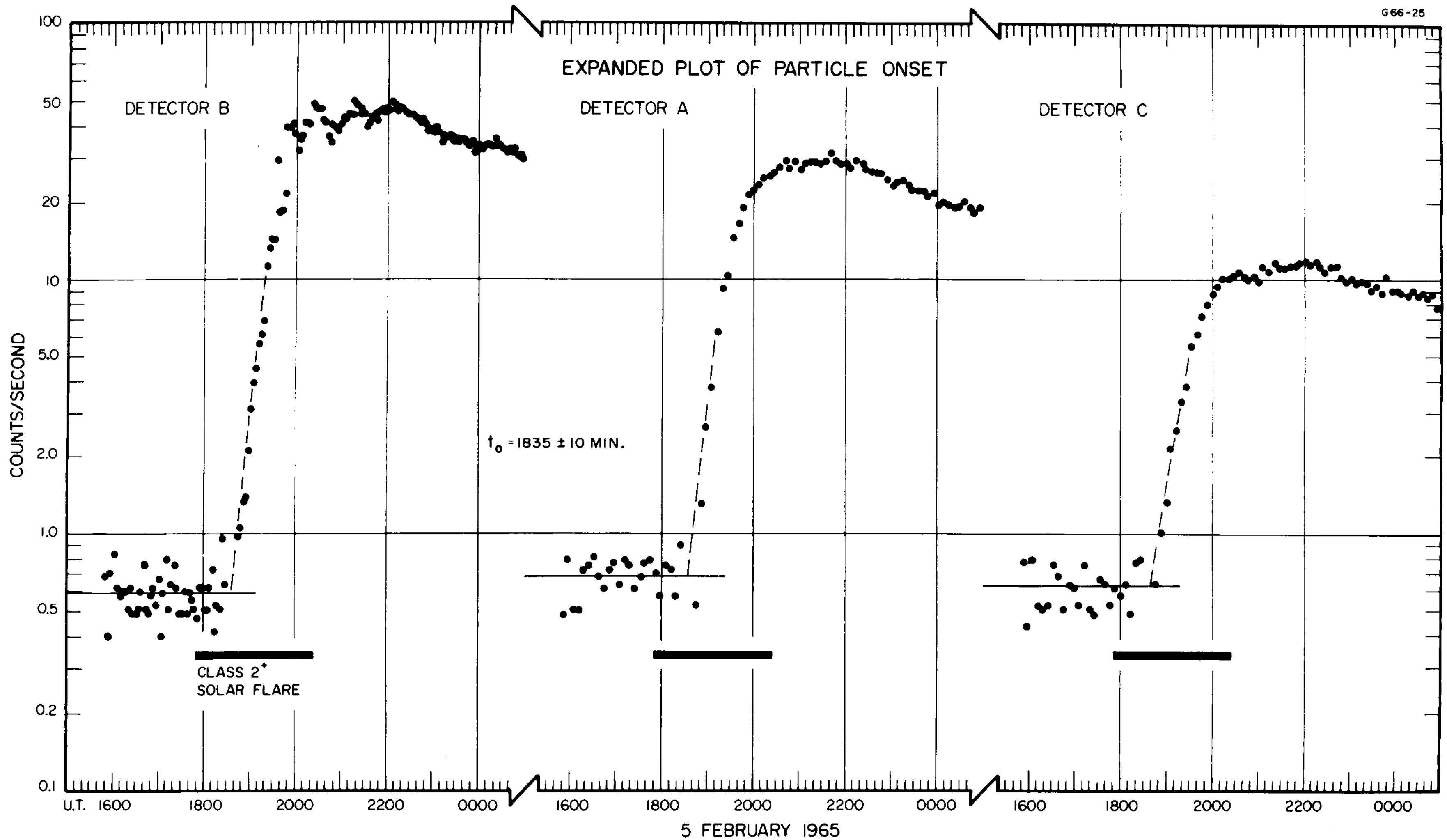

G66-25
EXPANDED PLOT OF PARTICLE ONSET
DETECTOR B
DETECTOR A
DETECTOR C
COUNTS/SECOND
100
50
20
10
5.0
2.0
1.0
0.5
0.2
0.1
t_0 = 1835 ± 10 MIN.
CLASS 2+
SOLAR FLARE
U.T. 1600
1800
2000
2200
0000
5 FEBRUARY 1965

Figure 2

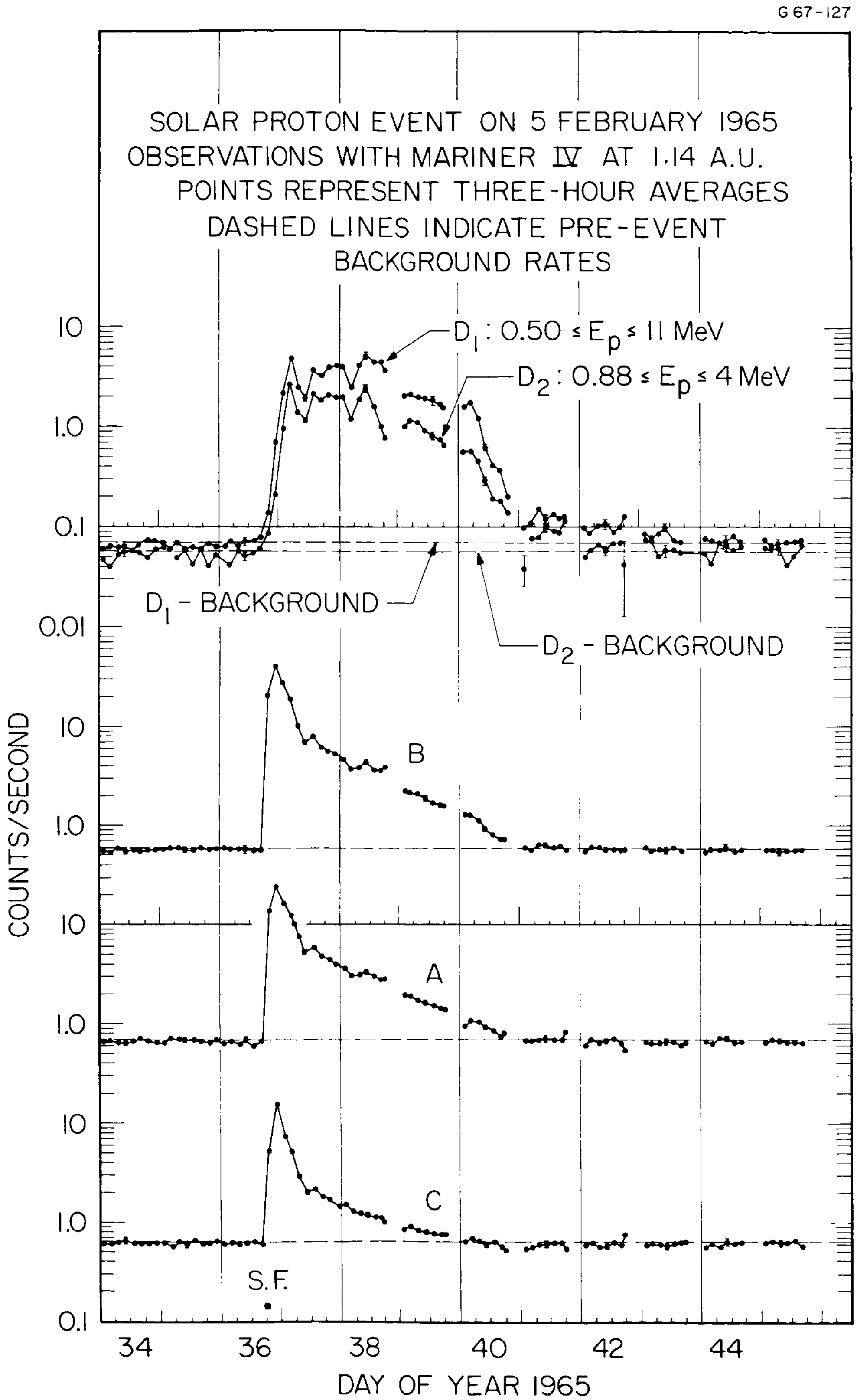
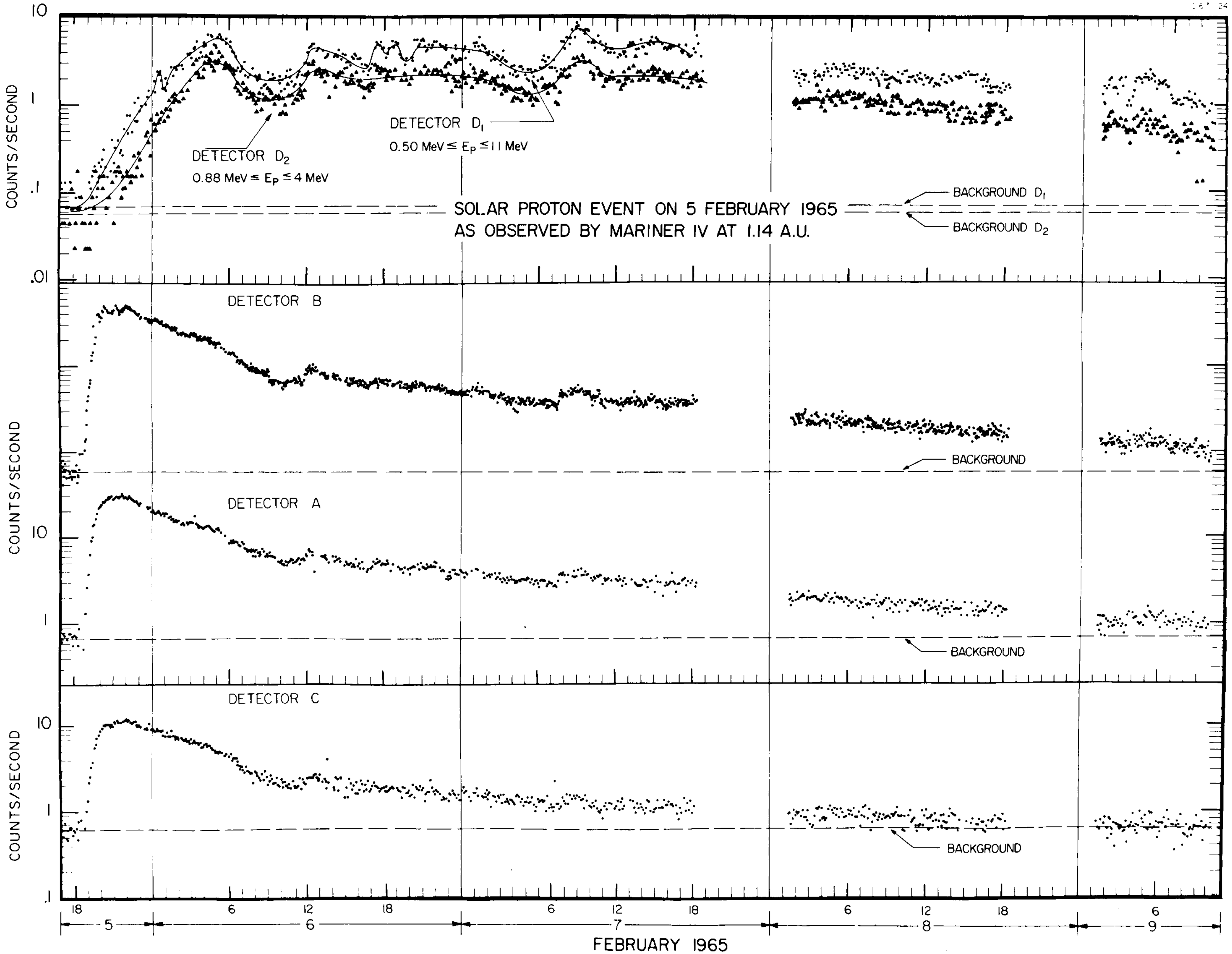

G 67-127
SOLAR PROTON EVENT ON 5 FEBRUARY 1965
OBSERVATIONS WITH MARINER IV AT 1.14 A.U.
POINTS REPRESENT THREE-HOUR AVERAGES
DASHED LINES INDICATE PRE-EVENT
BACKGROUND RATES
D_1 : $0.50 \le E_p \le 11$ MeV
D_2 : $0.88 \le E_p \le 4$ MeV
D_1 - BACKGROUND
D_2 - BACKGROUND
B
A
C
S.F.
COUNTS/SECOND
10
1.0
0.1
0.01
34
36
38
40
42
44
DAY OF YEAR 1965

Figure 3



SOLAR PROTON EVENT ON 5 FEBRUARY 1965
AS OBSERVED BY MARINER IV AT 1.14 A.U.
DETECTOR D_1
$0.50 \text{ MeV} \leq E_p \leq 11 \text{ MeV}$
DETECTOR D_2
$0.88 \text{ MeV} \leq E_p \leq 4 \text{ MeV}$
BACKGROUND D_1
BACKGROUND D_2
DETECTOR B
DETECTOR A
DETECTOR C
BACKGROUND
COUNTS/SECOND
10
1
.1
.01
100
FEBRUARY 1965
18
6
12
5
7
8
9

Figure 4

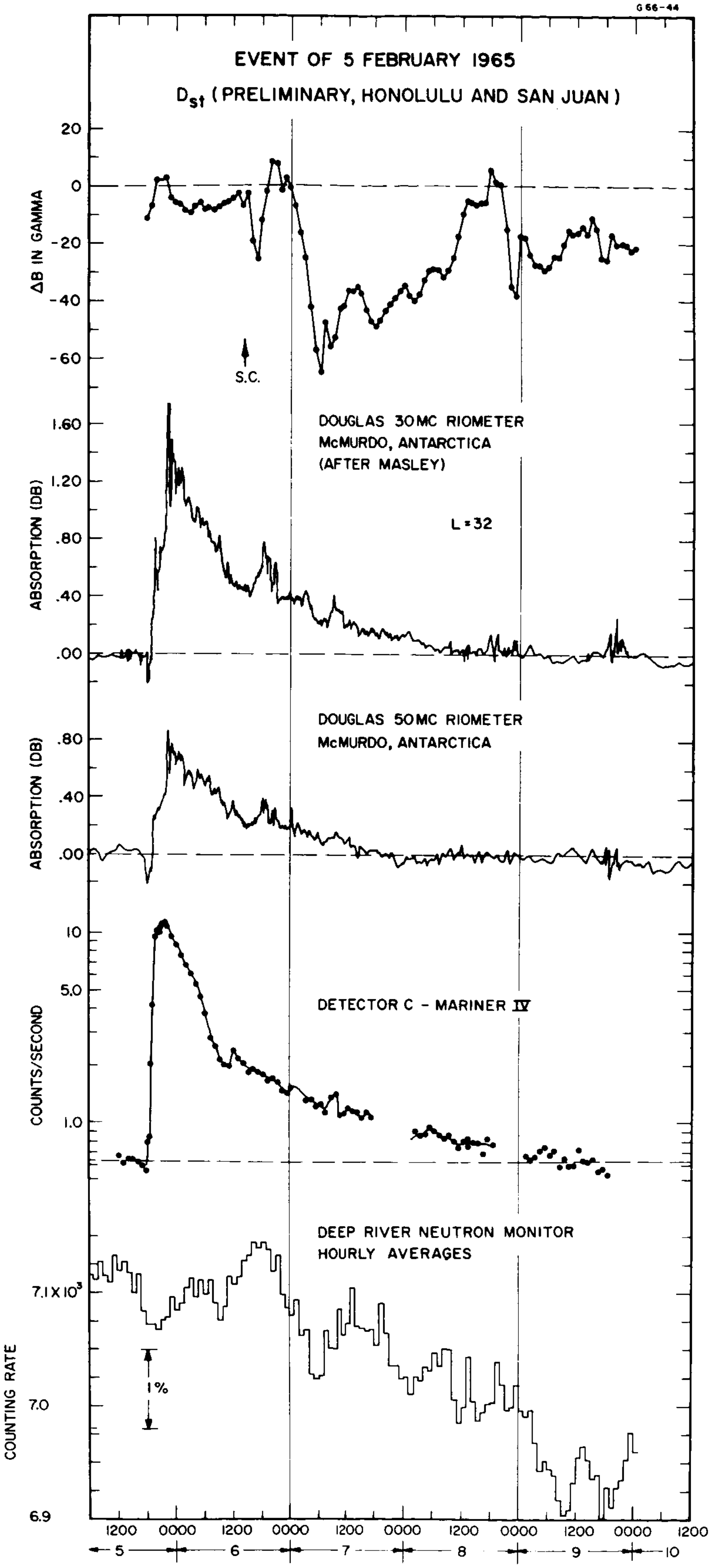
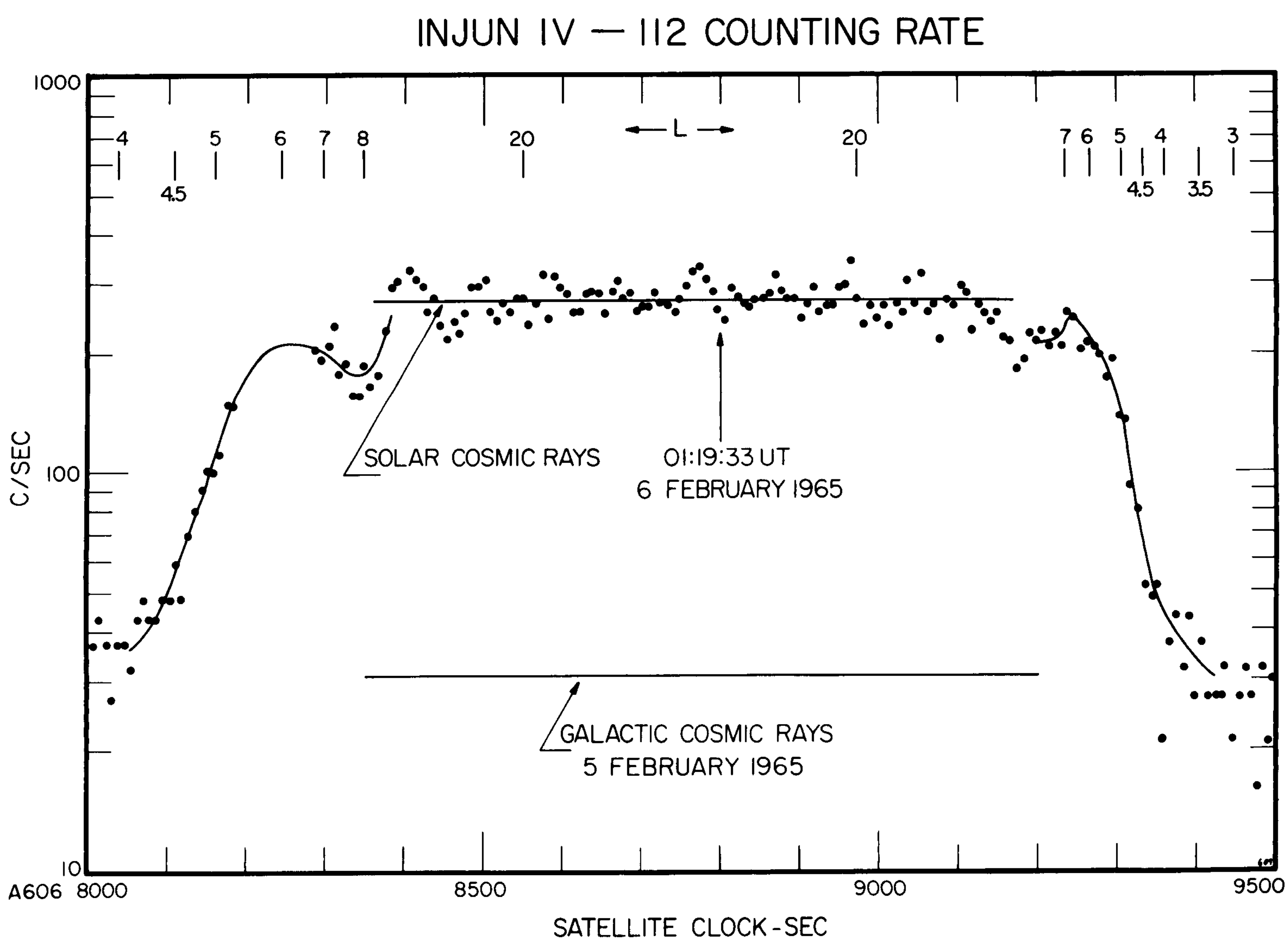

G66-44
EVENT OF 5 FEBRUARY 1965
D_{st} (PRELIMINARY, HONOLULU AND SAN JUAN)
ΔB IN GAMMA
20
0
-20
-40
-60
S.C.
DOUGLAS 30MC RIOMETER
McMURDO, ANTARCTICA
(AFTER MASLEY)
L = 32
ABSORPTION (DB)
1.60
1.20
.80
.40
.00
DOUGLAS 50MC RIOMETER
McMURDO, ANTARCTICA
ABSORPTION (DB)
.80
.40
.00
DETECTOR C - MARINER IV
COUNTS/SECOND
10
5.0
1.0
DEEP RIVER NEUTRON MONITOR
HOURLY AVERAGES
COUNTING RATE
7.1 X 10³
1%
7.0
6.9
1200
0000
1200
0000
1200
0000
1200
0000
1200
0000
1200
5
6
7
8
9
10

Figure 5



INJUN IV — 112 COUNTING RATE
1000
100
10
C/SEC
A606
8000
8500
9000
9500
SATELLITE CLOCK-SEC
4
4.5
5
6
7
8
20
← L →
20
7 6
5
4.5
4
3.5
3
SOLAR COSMIC RAYS
01:19:33 UT
6 FEBRUARY 1965
GALACTIC COSMIC RAYS
5 FEBRUARY 1965

Figure 6

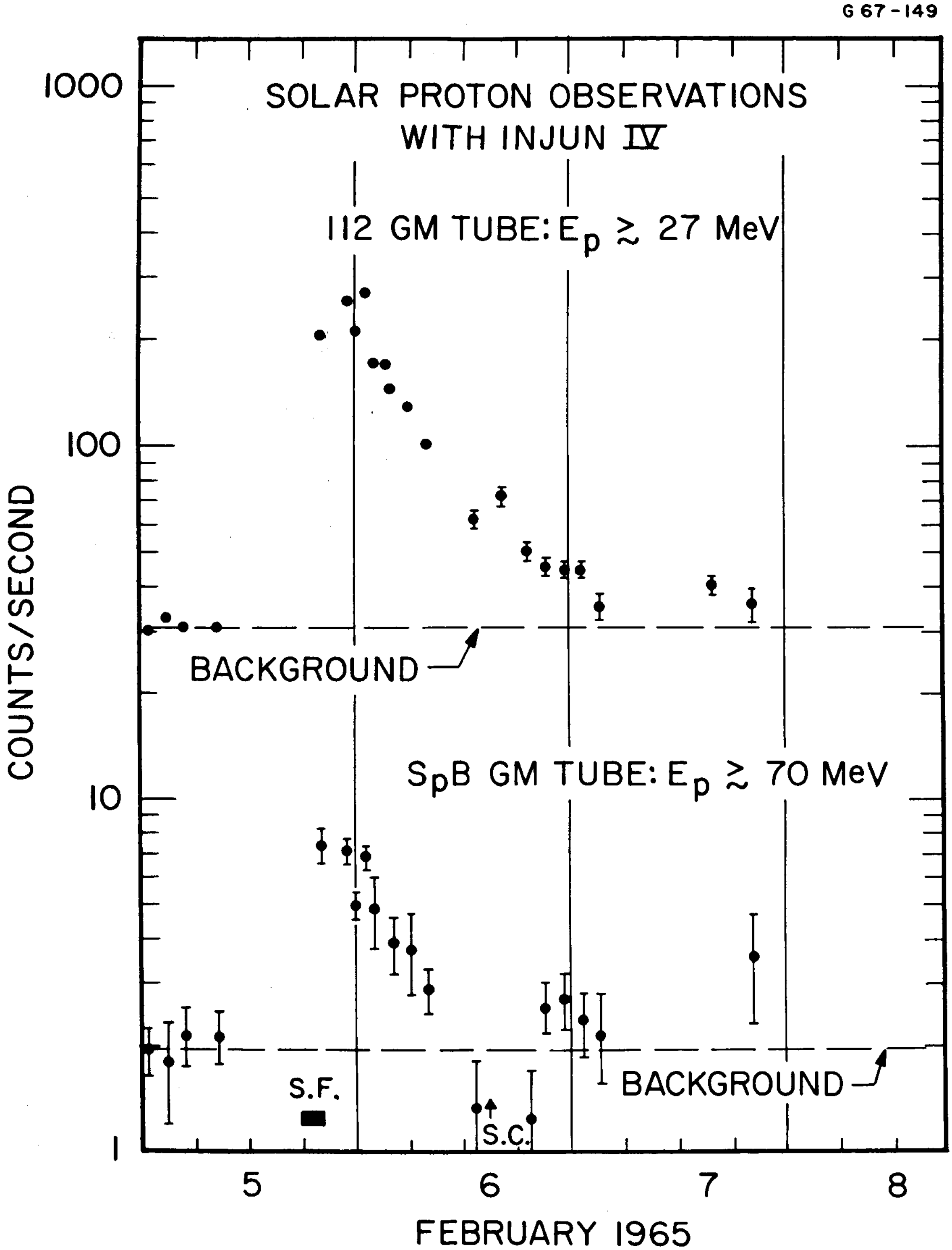

G 67-149
SOLAR PROTON OBSERVATIONS
WITH INJUN IV
112 GM TUBE: $E_p \gtrsim 27$ MeV
BACKGROUND
SpB GM TUBE: $E_p \gtrsim 70$ MeV
BACKGROUND
S.F.
S.C.
1000
100
10
1
COUNTS/SECOND
5
6
7
8
FEBRUARY 1965

Figure 7

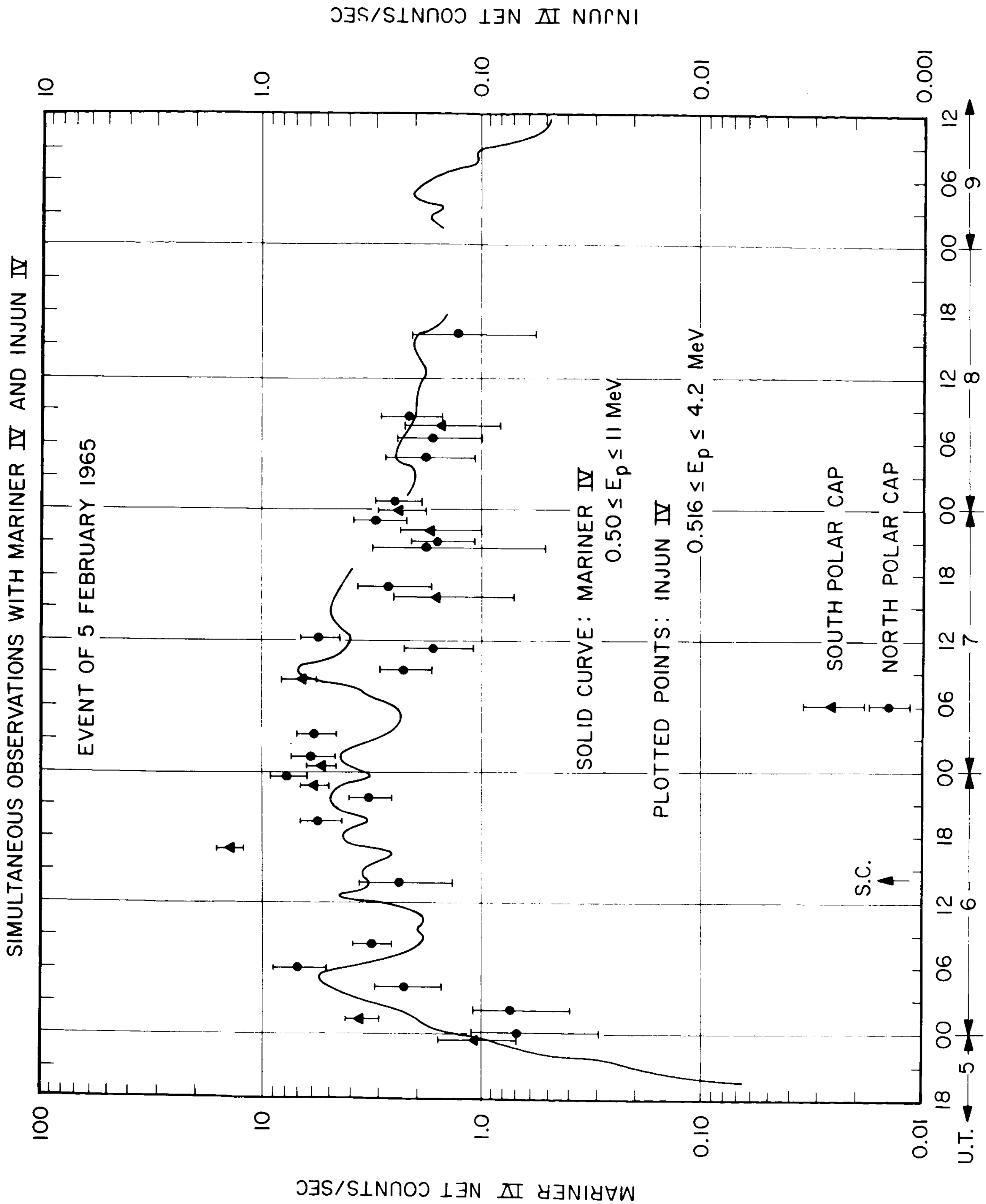

SIMULTANEOUS OBSERVATIONS WITH MARINER IV AND INJUN IV
EVENT OF 5 FEBRUARY 1965
SOLID CURVE: MARINER IV
0.50 ≤ E_p ≤ 11 MeV
PLOTTED POINTS: INJUN IV
0.516 ≤ E_p ≤ 4.2 MeV
SOUTH POLAR CAP
NORTH POLAR CAP
S.C.
INJUN IV NET COUNTS/SEC
10
1.0
0.10
0.01
0.001
MARINER IV NET COUNTS/SEC
100
10
1.0
0.10
0.01
U.T.
18
5
00
06
12
6
18
00
06
12
7
18
00
06
12
8
18
00
06
9
12

Figure 8

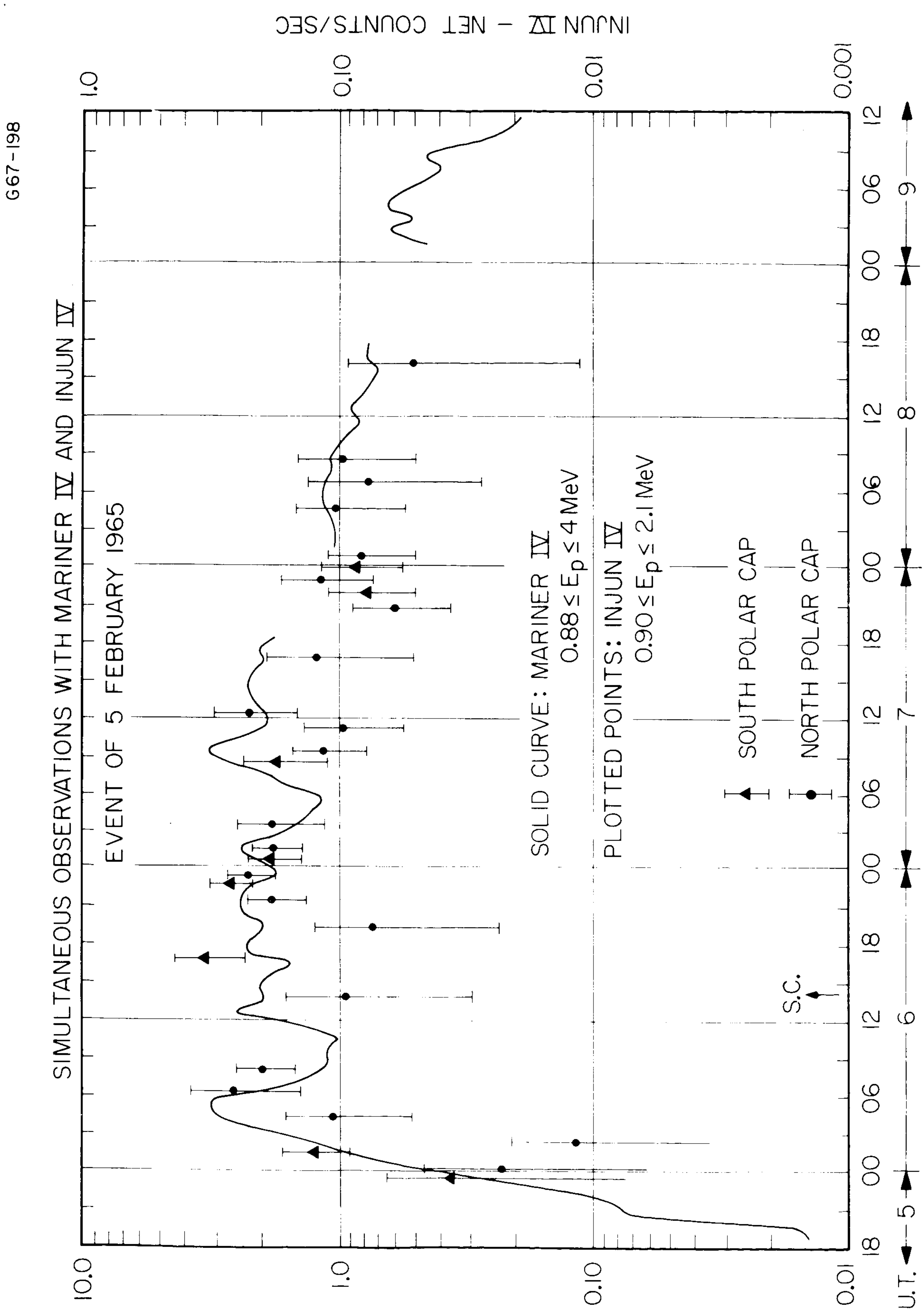
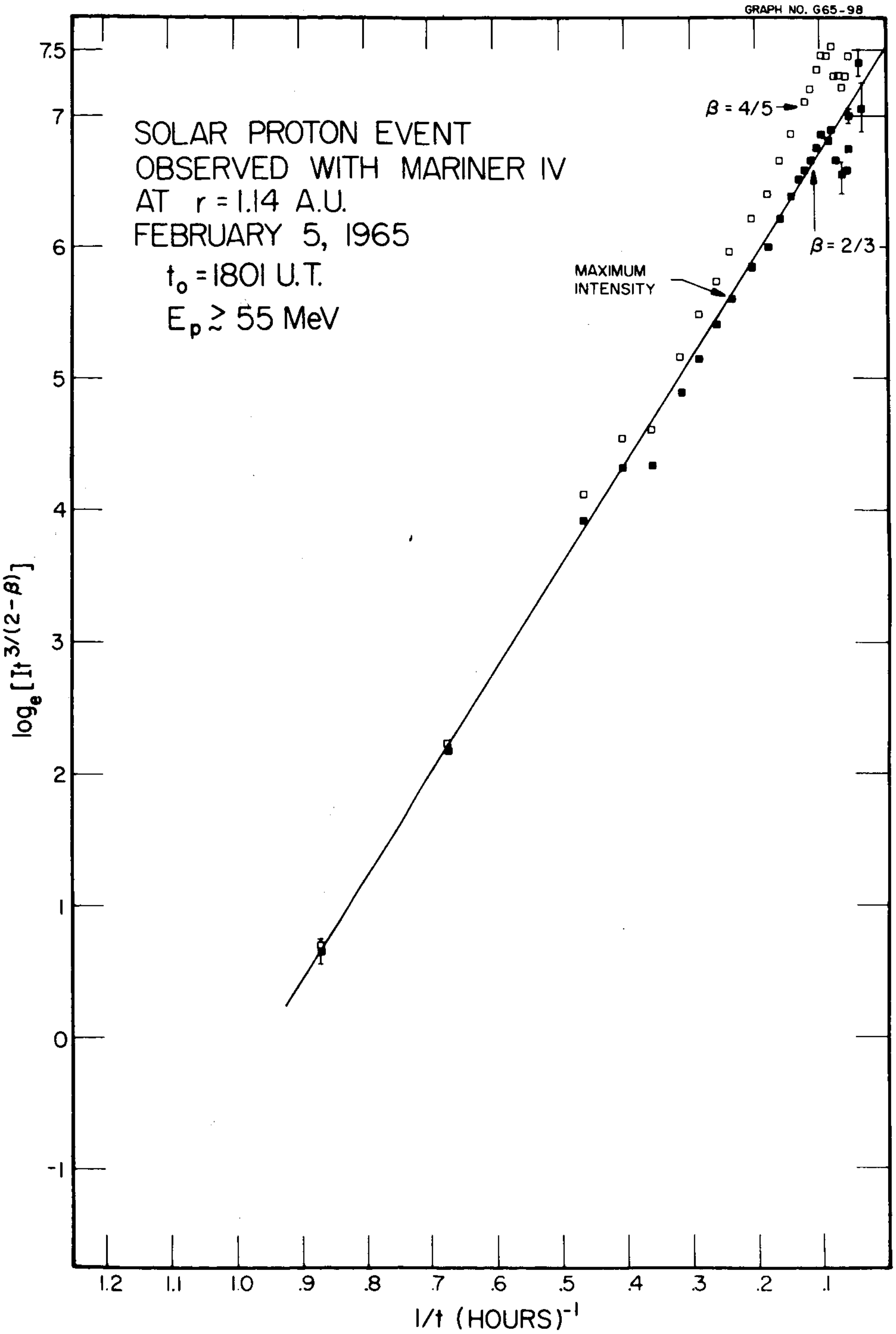

G67-198
SIMULTANEOUS OBSERVATIONS WITH MARINER IV AND INJUN IV
EVENT OF 5 FEBRUARY 1965
SOLID CURVE: MARINER IV
$0.88 \le E_p \le 4$ MeV
PLOTTED POINTS: INJUN IV
$0.90 \le E_p \le 2.1$ MeV
SOUTH POLAR CAP
NORTH POLAR CAP
S.C.
MARINER IV – NET COUNTS/SEC
INJUN IV – NET COUNTS/SEC
10.0
1.0
0.10
0.01
0.001
U.T.
18
00
06
12
5
6
7
8
9

Figure 9



GRAPH NO. G65-98
SOLAR PROTON EVENT
OBSERVED WITH MARINER IV
AT r = 1.14 A.U.
FEBRUARY 5, 1965
t_o = 1801 U.T.
$E_p \gtrsim$ 55 MeV
MAXIMUM INTENSITY
β = 4/5
β = 2/3
$\log_e [I t^{3/(2-\beta)}]$
1/t (HOURS)$^{-1}$

Figure 10

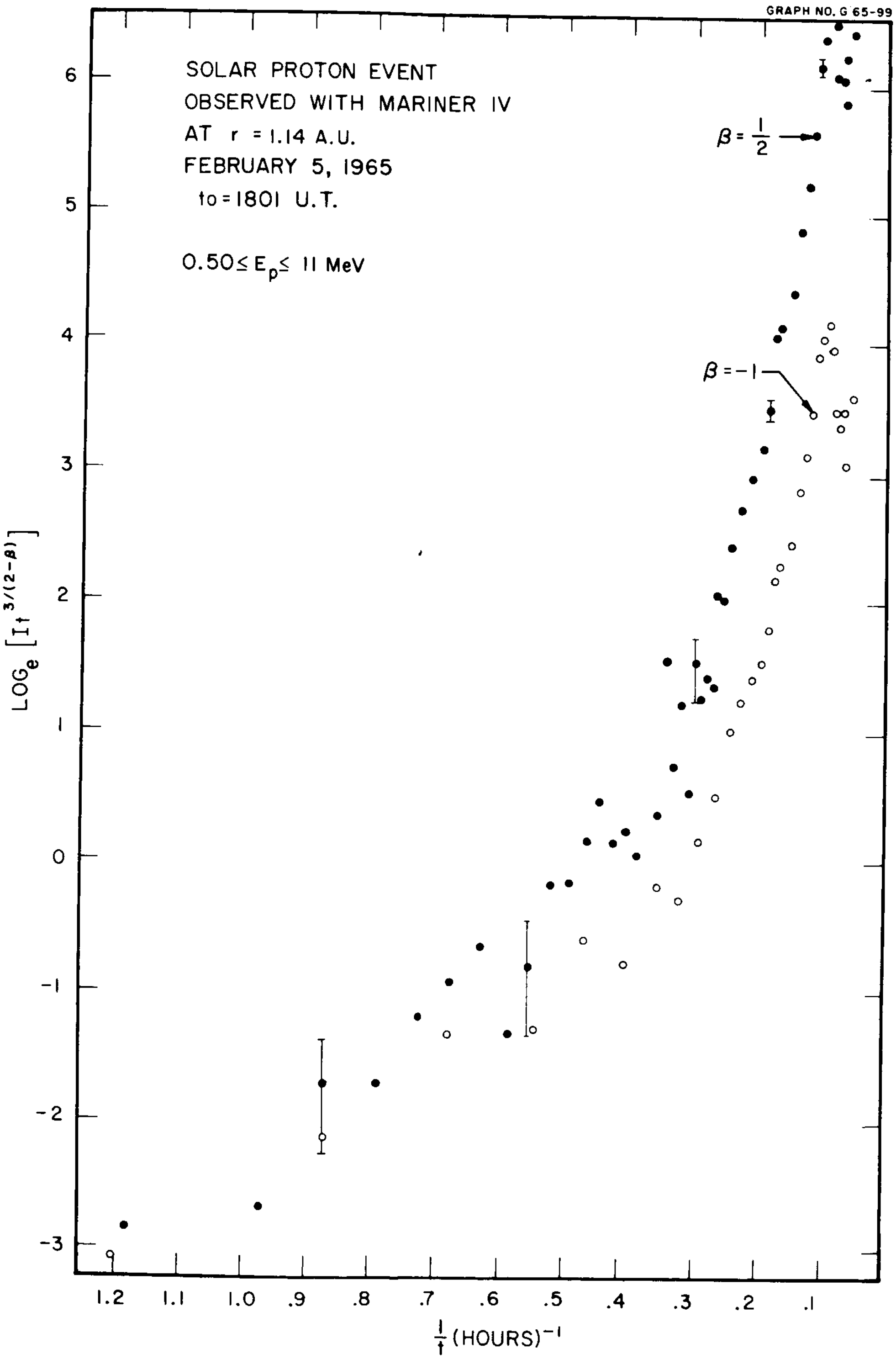

GRAPH NO. G 65-99
SOLAR PROTON EVENT
OBSERVED WITH MARINER IV
AT r = 1.14 A.U.
FEBRUARY 5, 1965
to = 1801 U.T.
0.50 ≤ E_p ≤ 11 MeV
β = 1/2
β = −1
LOG_e [I t^{3/(2−β)}]
1/t (HOURS)^{-1}

Figure 11

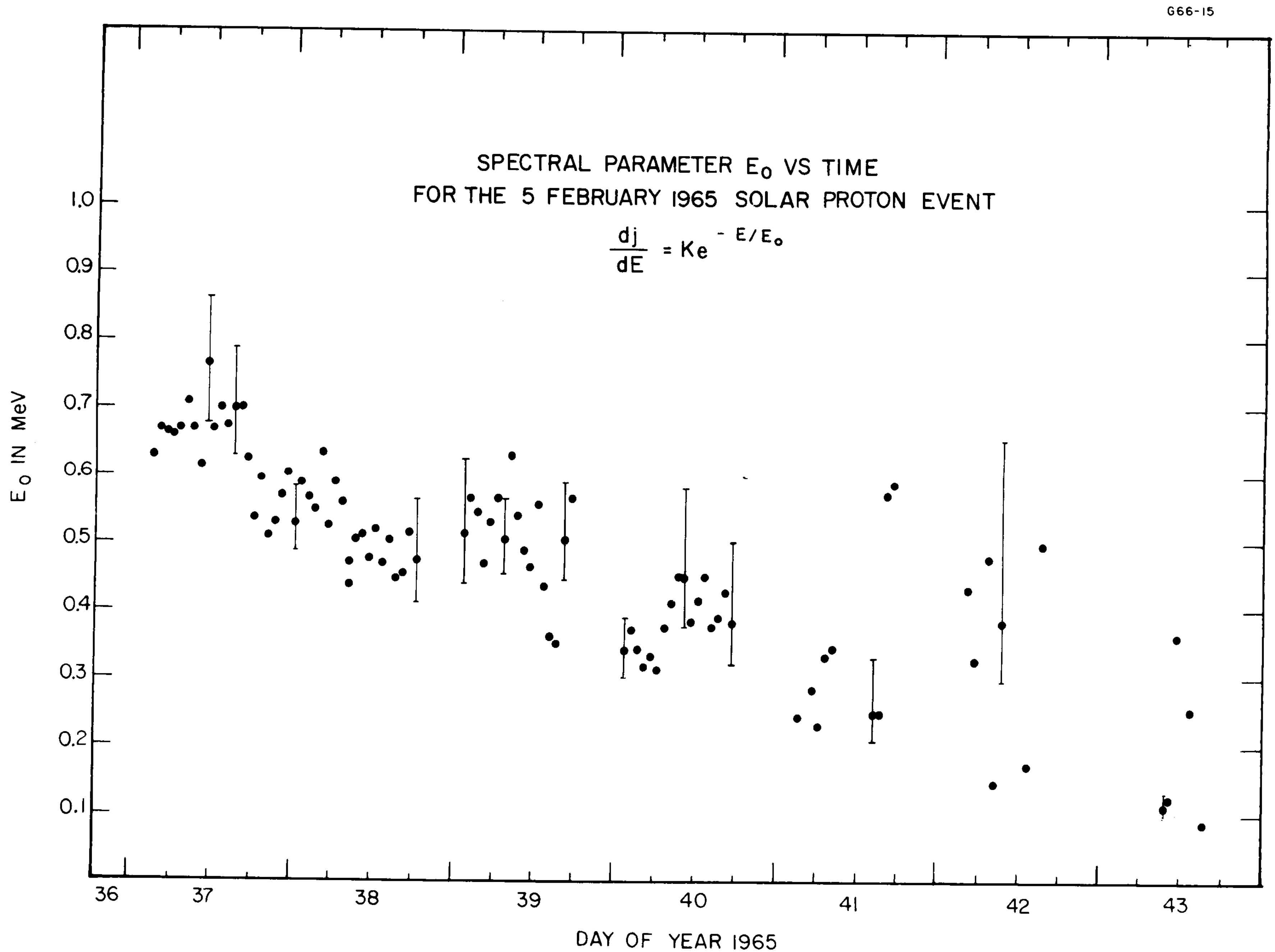

G66-15
SPECTRAL PARAMETER E_0 VS TIME
FOR THE 5 FEBRUARY 1965 SOLAR PROTON EVENT
$\frac{dj}{dE} = Ke^{-E/E_0}$
E_0 IN MeV
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
36
37
38
39
40
41
42
43
DAY OF YEAR 1965

Figure 12

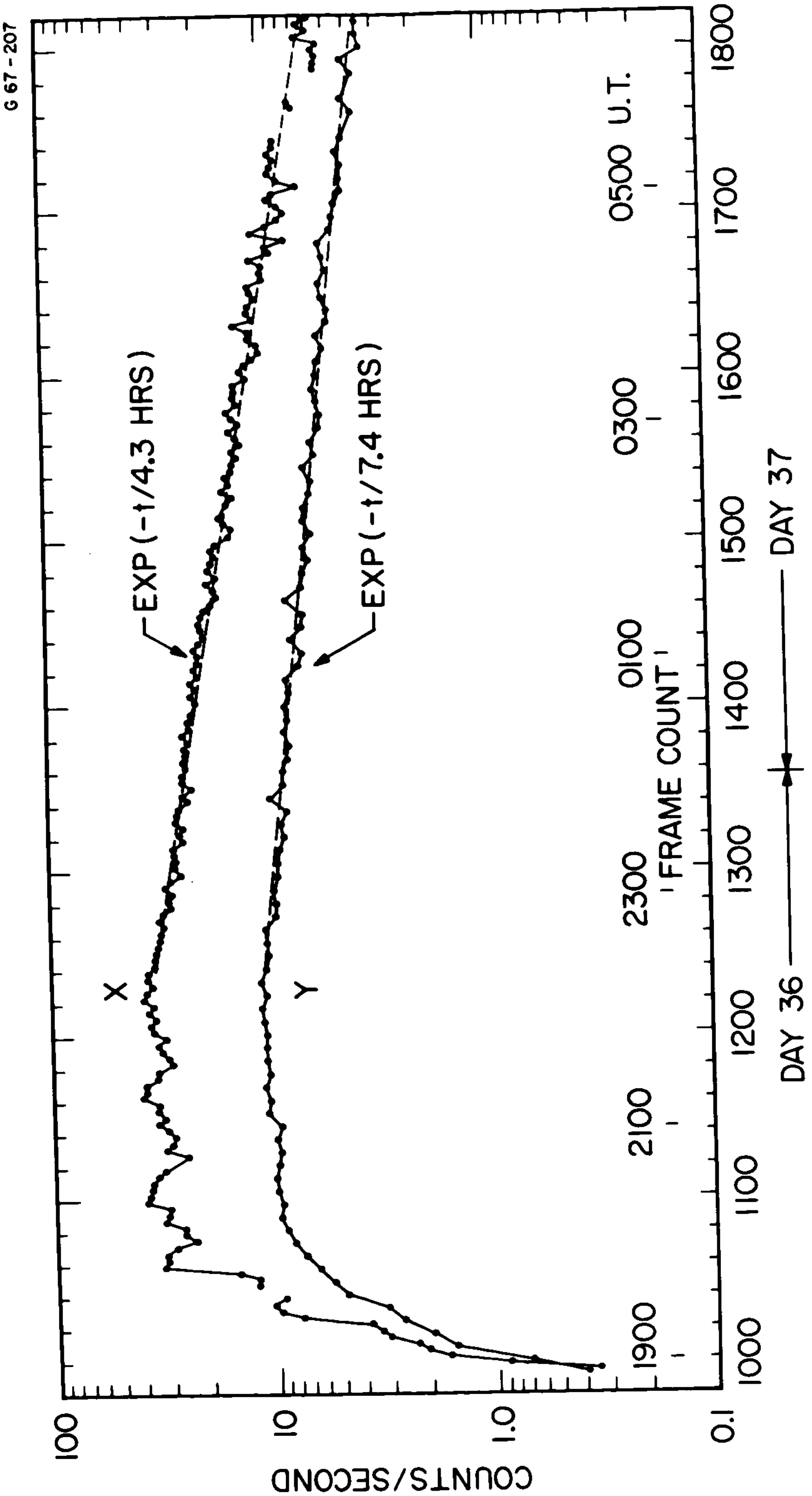

G 67 - 207
EXP (-t/4.3 HRS)
EXP (-t/7.4 HRS)
X
Y
COUNTS/SECOND
100
10
1.0
0.1
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2100
2300
0100
0300
0500 U.T.
'FRAME COUNT'
DAY 36
DAY 37

Figure 13